Update of the effect of the **crab cavities** on stability in the 8b4e case

*Effect of filling pattern*

N. Mounet

Effect of crab cavities on stability

Crab cavities high order modes (HOMs) may have an impact on stability if above a certain threshold:

![Vertical Impedance Per Cavity](image1)

**Figure 1: Vertical impedance per cavity.**

![Horizontal Impedance Per Cavity](image2)

**Figure 2: Horizontal impedance per cavity.**

From *J. Mitchell*, EDMS No [2488213](https://example.com), rev. 0.9 (HOM annex, LHC-ACFHC-ER-0004).

Thresholds from NM, 179th WP2 meeting (28/07/2020).
Effect of crab cavities – filling scheme

- These stability thresholds were evaluated for a full 25 ns beam (3564 bunches).
- High order modes involve coupled-bunch motion, which could depend on the exact filling scheme of the beam.

⇒ What is the impact of the filling scheme?
⇒ In particular what happens with the 8b4e scheme?

- The questions are simple but the answer are not easy to obtain:
  - Involves heavy PyHEADTAIL simulations (coupled-bunch with intrabunch motion), and rise time very slow (damper is in) → very long simulations (600’000 turns),
  - Vlasov solver option is also possible (since ~a week), but involves huge matrices to diagonalize.

⇒ Fully converged simulations (whole beam) would be a huge effort.
⇒ Attempt to provide here an approximate (~sufficient) answer.
Main impact of crab cavities

Crab cavities essentially increase the growth rate of modes:

⇒ We will check only the impact of the filling scheme on the growth rate.
Impact of filling scheme - vertical

- Relative difference (%) w.r.t. single-bunch & no crab:

  - $\beta^* = 140$ cm
  - $\beta^* = 40$ cm (only for crab)

- Simulations and theory not fully consistent, but not converged,
- Positive effect of crab in single-bunch,
- 8b4e is always more stable than full beam (or 288 bunches).

- $N_b=2.3e11$ p+/b
- $\varepsilon=2.1$ $\mu$m
- ADT gain: 100 turns
- bunch length (4xRMS)=$1.2$ ns
- Impedance model description in appendix
- Growth rates of main mode from SVD
Relative difference (%) w.r.t. single-bunch & no crab:

- $\beta^* = 140$ cm
- $\beta^* = 40$ cm

Many thanks to Carlo Zannini for providing an initial HL-LHC PyHEADTAIL script.

- $N_b=2.3e11$ p+/b
- $\varepsilon=2.1$ $\mu$m
- ADT gain: 100 turns
- bunch length (4xRMS)=1.2 ns
- Impedance model description in appendix
- $\beta^* = 140$ or 40 cm (only for crab)
- Growth rates of main mode from SVD
Impact of filling scheme on stability is still a subject of study and requires a very strong simulation and theoretical effort, in general.

Simulations and theory not yet fully consistent, but both were not pushed to convergence yet.

First results seem to show that in the case of crab cavities, the worst case scenario is still always the full 25 ns beam; in any case the 8b4e seems not to be a concern.
Appendix
HL-LHC impedance model

- **HL-LHC model:**
  - With optics v1.5, $\beta^*=140$ cm (except crab cavities when indicated $\beta^*=40$ cm),
  - **Collimator** at almost full upgrade (jaws of 2 TCPs and all but 2 TCSs in IR7 replaced by Mo-graphite ones, Mo-coated for the TCSs); some TCTs in Cu-coated copper-diamond; tungsten TCLD absorber in IR7,
  - Updated collimator tapers (**S. Antipov**, **E. Carideo**),
  - Beta functions in the arcs and triplets (optics v1.4),
  - **TDIS** (with graphite, Ti$_6$Al$_4$V and CuCr1Zr),
  - New MKI-cool – 4 of them,
  - New **octogonal beam screens** in triplets, with up-to-date dimensions, aC-coating, 75K copper, pumping holes and welds (**accurate weld & shape factors** from **C. Zannini**),
  - Updated experimental chambers (ATLAS & CMS),
  - Tapers and BPMs in the triplets region,
  - **Crab cavities** (**DQW: April 2019, RFD: Nov. 2019**),
  - Deformable RF-fingers, VAX and Y-chambers in triplet region (including **new design for DRF in crab cavities** – **B. Salvant**),
  - **VELO** (**N. Biancacci** et al – **Elba, 30th May 2017**).
Retracted collimator settings

Collimator settings **B1** (\( \sigma \) computed with \( \varepsilon = 2.5 \mu \text{m.rad} \)) at flat top:

<table>
<thead>
<tr>
<th>Collimators</th>
<th>Half-gap [( #\sigma ), ( \beta^* = 140\text{cm} ) ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP/TCS/TCLA(D) IR7</td>
<td>8.5 / 10.1 / 13.7 (16.6)</td>
</tr>
<tr>
<td>TCP/TCS/TCLA IR3</td>
<td>17.7 / 21.3 / 23.7</td>
</tr>
<tr>
<td>TCDQ/TCS IR6</td>
<td>11.6</td>
</tr>
<tr>
<td>TCT H4/V4/H6/V6 – IR1</td>
<td>29.8 / 37.0 / 24.0 / 41.9</td>
</tr>
<tr>
<td>TCT H4/V4/H6/V6 – IR5</td>
<td>29.9 / 37.0 / 24.1 / 42.2</td>
</tr>
<tr>
<td>TCL Q4/Q5/Q6 – IR1</td>
<td>46.2 / 56.3 / 44.8</td>
</tr>
<tr>
<td>TCL Q4/Q5/Q6 – IR5</td>
<td>46.3 / 56.5 / 43.2</td>
</tr>
<tr>
<td>TCT IR2/8</td>
<td>35.4 / 17.7</td>
</tr>
</tbody>
</table>

Note: injection protection collimators and TCLD in IR2 are all in parking position.